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The Relationship Between Acoustic Target Strength and Body Length for Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*)

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PURPOSE: This technical note presents the results of field measurements of acoustic target strength (TS) for Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) of known total length (TL). An established relationship between TS (dB) and TL (cm) is a fundamental requirement of fishery hydroacoustic investigations. Equations describing relationships for Atlantic sturgeon of selected size ranges were derived for two ultrasonic frequencies (200 and 420 kHz) using a digital split-beam sonar directed vertically at tethered sturgeon. Species-specific TS-TL equations are necessary to provide accurate density or abundance estimates, fish length frequency distributions, and to potentially differentiate sturgeon from other fish species during fisheries hydroacoustic surveys.

BACKGROUND: The range of the Atlantic sturgeon extends from Labrador, Canada, to the St. John's River, Florida. They are found in rivers, estuaries, and coastal waters. Atlantic sturgeon commonly attain lengths of up to 79 in. (200 cm), although the largest historical record was for an adult that weighed 811 lb and was 14 ft long. Life expectancy ranges from 50 to 75 years. General accounts of sturgeon feeding portray them as opportunistic benthivores, feeding primarily on mollusks, polychaete worms, amphipods, isopods, shrimp and small bottom-dwelling fishes and insect larvae (Gilbert 1989; Smith 1985). The Atlantic sturgeon is anadromous, entering freshwater rivers to spawn at water temperatures ranging from 13.2 to 23 °C. This occurs in spring through early summer; typically February-March in the southern portion of its range and May-July in Canada (Smith 1985; Bain 1997; Smith and Clugston 1997). Substrate is a key spawning habitat parameter for Atlantic sturgeon, as hard bottom (small rubble, gravel, hard clay, and limestone) is required for successful egg attachment and incubation, while also protecting larvae from predators (Smith and Clugston 1997). Atlantic sturgeon may remain in fresh or brackish waters until they reach 2.5 to 3 ft in length. Juveniles can remain in riverine and estuarine systems for periods of 1 to 6 years before migrating to the coast and onto the continental shelf where they grow to maturity. Since juveniles are known to congregate at fresh and saltwater interfaces, these areas may serve as juvenile nursery habitat. Important habitats for Atlantic sturgeon include spawning areas, estuarine nursery areas, inlets that act as migration corridors to and from freshwater spawning habitat, and nearshore wintering grounds for adult and older juveniles. McCord (2003) reported that Atlantic sturgeon overwinter in deep channels and holes within coastal sounds and bays. Thus a variety of coastal, estuarine, and riverine habitats are used by Atlantic sturgeon during various life stages and are necessary for species survival. Knowledge gaps identified by the Atlantic State Marine Fisheries Commission include: identifying and mapping spawning locations; identifying wintering habitat of sub-adults; habitat usage during non-spawning seasons; determining methods to quantify population abundance and habitat requirements; and potential negative impacts associated with dredging. Detailed reviews on the status, life history, and ecology of the Atlantic sturgeon can be found in Smith (1985); Gilbert (1989); Bain (1997); Smith and Clugston (1997); Waldman and Wirgin (1998); Dadswell (2006); and the Atlantic Sturgeon Status Review Team (2007).

Potential Impacts of Dredging on Sturgeon. The majority of navigable waters in the United States are inhabited by one or more species of sturgeon. Several sturgeon species have affinities for channel bottoms, and may congregate in depressions or deep holes. Concerns that dredging operations within estuarine and riverine waterways negatively impact sturgeon species have existed for decades. Regulatory agencies frequently recommend conservative management practices (e.g., environmental windows), although data on the potential interactions between dredging operations and sturgeon are generally lacking. Dredging-related concerns involving sturgeon include physical disturbance of spawning activities, destruction or modification of spawning habitat or substrate, intolerance of elevated sedimentation or turbidity conditions, disruption of migration activities, impacts on benthic macrofaunal communities, and hydraulic or mechanical entrainment. According to Smith and Clugston (1997), dredging and filling can potentially impact habitats used by Atlantic sturgeon. Hydraulic and mechanical dredge entrainment of a variety of fish species have been the focus of many studies (e.g., Armstrong et al. 1982; Larson and Moehl 1990; McGraw and Armstrong 1990; Buell 1992). Buell (1992) reported the hydraulic entrainment of a substantial number of juvenile white sturgeon (entrainment rate 0.015 fish/cy, size class 300 to 500 mm), from a location referred to as the local “sturgeon hole.” Dickerson (2005) summarized entrainment of sturgeon or “takes” from dredging activities with observer programs. Through 2005, a total of 24 sturgeon takes (Gulf = 2, Shortnose = 11, Atlantic = 11) have been recorded. Of the 11 Atlantic sturgeon mortalities, the majority were associated with hopper dredging (n=7), followed by clamshell (n=3) and pipeline (n=1) dredging. Several studies indicated that sturgeon tend to avoid areas that have recently been dredged, but may be attracted to areas of active dredged material placement. In a recent status review of Atlantic Sturgeon, McQuinn and Nellis (2007) reported avoidance issues for both lake and Atlantic sturgeon at dredged material placement sites. In the same report, Hatin et al. (2007) tested whether dredging operations affected Atlantic sturgeon behavior by comparing CPUE before and after dredging events in 1999 and 2000. The authors concluded that there was a sevenfold reduction in Atlantic sturgeon presence after dredging activities began, indicating that sturgeon were actively avoiding these areas.

Existing Knowledge: Estimating fish abundance is a basic fisheries management need. Although many quantitative methods (e.g., tag and release programs or trawling/netting) are used to gather information on stock or population abundance, these techniques are frequently labor-intensive and costly. Hydroacoustic methods represent an effective alternative to conventional survey techniques in terms of greatly enhanced spatial and temporal coverage at comparable cost, as well as provision of quantitative measurements of fish density or biomass, directional movement, and size. However, one limitation in the use of fisheries acoustics is species identification. Typically, taxonomic identification of acoustic targets is inferred through the use of supplementary information such as location in the water column, net catch data, and knowledge of a species’ habitat usage (Horne 2000). Effective use of fisheries acoustics is dependent on an understanding of the relationship between TS and fish length for the dominant species found within the system surveyed. This relationship forms a critical assumption underlying accurate estimates of density and size frequency distribution. This relationship also forms a basis for exploration of better means of acoustic target species identification. Target strength or acoustic size is a measure of the capability of a fish to reflect sound energy. One of the first studies to relate target strength to fish size was undertaken by Love (1971). Dorsal-aspect target strength was obtained from eight species (including Atlantic menhaden, *Brevoortia tyrannus*, and bay anchovies, *Anchoa mitchilli*) ensonified at frequencies ranging from 12 to 200 kHz. This relationship is summarized in the equation 19.1Log (Length (ft)) + 0.9Log (Wavelength (ft)-34.2, which is generally referred to as "Love's-Dorsal Aspect-1971." Although Love's equation has been widely accepted and is generally suitable for many applications, it has not been thoroughly tested across a wide range of species or systems (Hartman and Nagy 2005). Foote (1987) examined in situ measurements of fish target strength for use in acoustic surveys. Target strength to fish length relationships were developed for fishes with closed swimbladders (TS =20logL-67.4) and clupeoids (TS = 20logL-71.9). Differences were detected between the two categories at 38-kHz frequency; hence the variability in TS was attributed to the swimbladder type. Recent studies have examined the relationship of target strength to length in both in situ and controlled laboratory conditions for a wide range of species, including juvenile perch (*Perca fluviatilis*), brown trout (*Salmo trutta*) and rainbow trout (*Onchorhynchus mykiss*), Atlantic salmon (*Salmo salar*), striped bass (*Morone saxatilis*), orange roughy (*Hoplostethus atlanticus*), Atlantic cod (*Gadus morhua*), Atlantic mackerel (*Scomber scombrus*), alewife (*Alosa pseudoharengus*), white perch (*Morone americana*), walleye pollock (*Theragra chalcogramma*), Atlantic redfish (*Sebastes* spp.), Atlantic herring (*Clupea harengus*), and rainbow smelt (*Osmerus mordax*) (Clay and Castonguay 1996; Kubecka and Duncan 1998; Gauthier and Rose 2001; Warner et al. 2002; Horne 2003; McQuinn and Winger 2003; Rudstam et al. 2003; Frouzova and Kubecka 2004; Nero et al. 2004; Hartman and Nagy 2005; McClatchie and Coombs 2005). A comprehensive summary of existing TS-Length equations can be found in Simmonds and MacLennan (2005).

Recently researchers have begun to examine the influence of morphology, physiology, and ontogeny on TS-length relationships, using factors such as body depth, presence or absence of a swimbladder, marine or freshwater species, dead (or stunned) versus live fish, fish orientation to the transducer beam, tilt angle, and whether the fish is tethered or free swimming (Gauthier and Rose 2001; Francis and Foote 2003; Horne 2003; McQuinn and Winger 2003; Clay and Horne 1994). Simmonds and MacLennan (2005) describe three experimental techniques for measuring target strengths of fishes: 1) immobilized and unconscious specimens, 2) actively swimming, but confined in a cage or net impoundment, and 3) free swimming in their natural environment. In Love's (1971) study, data for freshwater and marine species were presented together, data for species with swimbladders were combined with non-swimbladder species, and no distinction was made between dead and live fishes. Combining these parameters may have introduced significant artifacts into the derived TS-Length relationship (Foote 1979; McClatchie et al. 1996). Differences in target strength between dead or stunned fishes and swimming fishes have been reported by MacLennan (1981). Differences may also arise from the effects of feeding state, gonad development and pressure (or depth) on the volume of the swimbladder (Ona 1990). As summarized in Hazen and Horne (2003), each of these factors was shown to influence TS by as much as 5 dB. Foote (1980) noted that an air-filled swimbladder can contribute up to 90 percent of the backscattered sound. By far the greatest number of target strength measurements has been made on marine fishes with swimbladders, using a dorsal-aspect measurement of target strength. A few studies, primarily in riverine environments, have measured "side-aspect" target strength (Burwen and Fleischman 1998; Frouzova et al. 2005). Side-aspect target strength data have become increasingly important in applications where migrating fish are ensonified from a fixed transducer near the riverbank. Side-aspect target strength is related to fish size (Love 1969; Kubecka and Duncan 1998), but variable fish orientation and high levels of acoustic noise in rivers can result in excessive measurement error. Attempts to use side-aspect target strength in riverine acoustic applications to discriminate between fish species has been unsuccessful, and applications have been largely confined to systems where a single species is numerically dominant (Daum and Osborne 1998). Another factor affecting target strength is the vertical orientation or tilt angle of ensonified fish. McQuinn and Winger (2003) measured the effects of change in tilt angle on TS during diel vertical migrations of Atlantic cod (*G. morhua*) over a several-day period. TS for Atlantic cod varied as the species rose from the ocean bottom during the evening hours, increasing their tilt angle. Hazen and Horne (2003) considered tilt angle to be the most important factor that influences variability in TS. They examined the effects of tilt angle, body length, and depth on TS of walleye pollock (*T. chalcogramma*) and concluded that although length is often the main factor in TS regressions, the influence of tilt angle and transducer frequency on TS is greater than that of length per unit change. They listed the order of importance as tilt angle > frequency > length > depth. Foote (1980) reported as much as a 30-dB change in TS with a tilt change of 45 deg. A retrospective evaluation of relationships between fish size, acoustic frequency, and target strength can be found in McClatchie et al. (1996), who attempted to compare estimation methods of dorsal-aspect target strength and combined data for multiple studies involving 33 fish species into general relations between fish size, acoustic frequency and target strength.

To the authors' knowledge, only a single study (Nealson and Brundage 2007) has been reported in the scientific literature examining the relationship between TS and TL for any species of sturgeon. Actual measured lengths of shortnose sturgeon (*Acipenser brevirostrum*) diverged significantly from values calculated based on Love's (1971) equation. Results may have reflected orientation of specimens restrained in gill nets during the measurements. Love's (1971) equation yielded TL estimates between 71 and 83 cm for specimens that were actually between 82 and 128 cm TL.

Given the unique morphology of sturgeon species, their decline in numbers, and protected status in many systems, establishing an accurate TS-TL relationship represents an important step in expanding tools for determining sturgeon density, length frequency distributions, and spatial distribution patterns. This note presents the findings of investigations of target strength of Atlantic sturgeon. In particular, the use of two ultrasonic frequencies was examined to determine if multiple frequencies in tandem could provide additional insights into species discrimination. Future efforts will focus on refining the TS-TL equation through testing of multiple sturgeon species and size classes. Efforts reported herein represent one component of a larger study initiated in 2007 by a partnership among the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Engineer Norfolk District, Virginia Commonwealth University (VCU), Virginia Sea Grant, U.S. Fish and Wildlife Service (USFWS), and the James River Association Riverkeeper Program. The broader partnership study objectives include filling knowledge gaps pertaining to Atlantic sturgeon migratory corridors and behavior, spawning habitat, population abundance (density), diel movements, and potential impacts, if any, of dredging operations.

Ongoing studies employ a combination of fisheries hydroacoustics surveys, conventional netting techniques, and active and passive biotelemetry in the James River, Virginia.

METHODS:

Study Area. The James River is Virginia's largest river, flowing across the entire state from inland headwaters of the Cowpasture and Jackson Rivers in Bath and Highland Counties to its entrance into the Chesapeake Bay at Hampton Roads. The river is the largest tributary to the Chesapeake Bay and is 340 miles long, encompassing a watershed of approximately 10,000 square miles. The Watershed is comprised of three sections: the Upper James Watershed begins in Allegheny County and travels through the Allegheny and Blue Ridge Mountains as far as Lynchburg, the Middle James runs from Lynchburg to the fall line in Richmond, and the Lower James stretches from the fall line to the Chesapeake Bay. Tethering studies occurred just off the main channel of the James River in an area known as the Dutch Gap Cutoff (Figure 1). This area is located upstream of Turkey Island, and northeast of Farrer and Hatcher Islands at 37° 23.05'N and 77° 22.46"W.

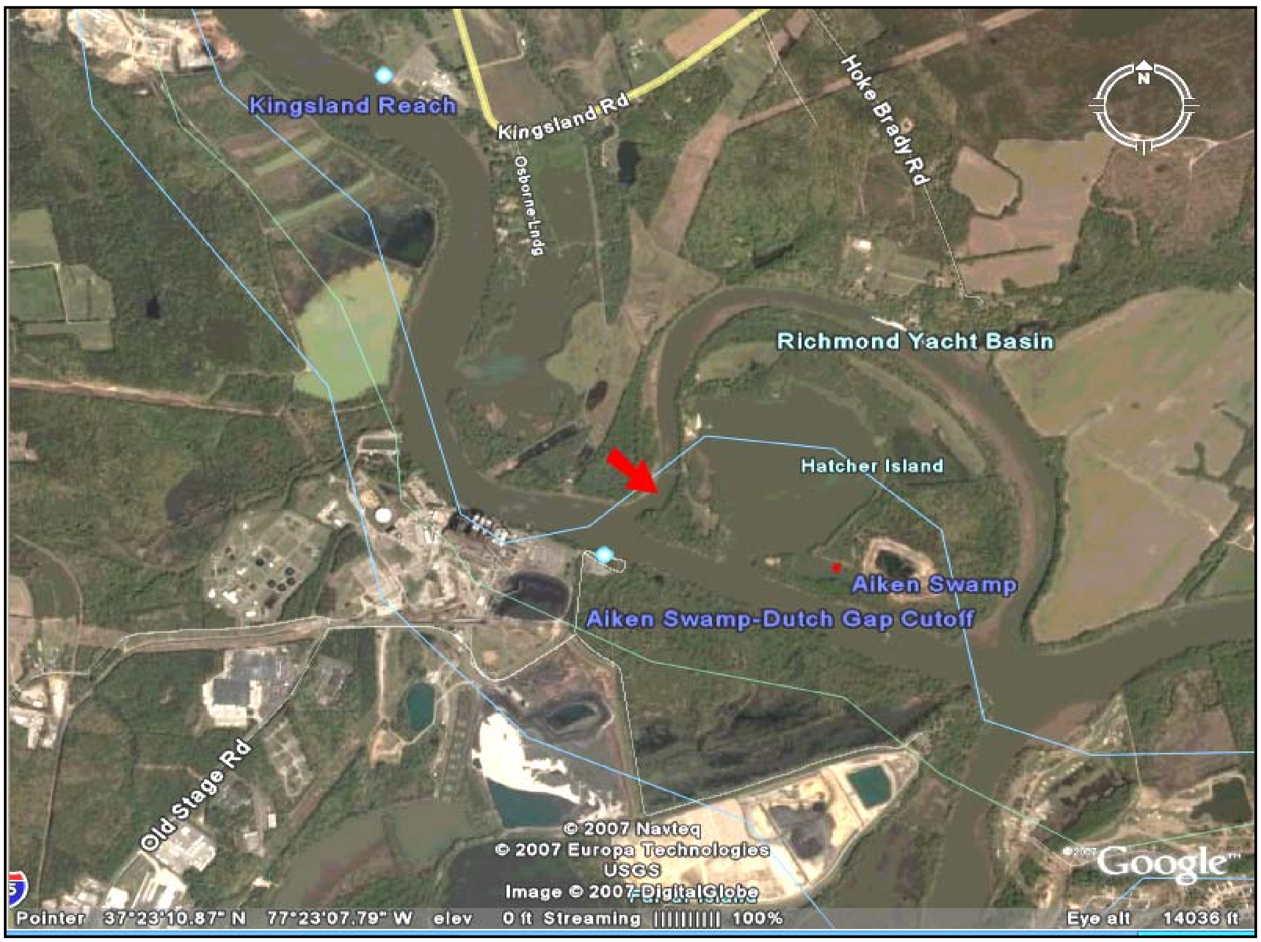

Figure 1. Study site (Image credit: Google Earth). Arrow indicates location of a deep hole in which tethering experiments were conducted.

Hydroacoustics System. Two separate BioSonics Inc. scientific grade split-beam echo-sounding systems were used in the tethering experiments. The first consisted of a DT 6000 200-kHz digital transducer with a 6-degree beam, signal processor, interface box, and data logging equipment. The second consisted of a DT 6000 420-kHz transducer with a 10-degree beam angle in a similar configuration.

Prior to fieldwork both hydroacoustic systems had undergone factory calibration using a reference-standard transducer to derive Source Level (SL), Receiver Sensitivity (RS) and transducer beam pattern and side lobe characteristics. An in situ calibration was performed to verify the system performance as affected by site-specific conditions such as water temperature, salinity, and operating depth. The field calibrations were performed using a standard target with known target strength (TS) using the following protocol. For the 200-kHz system, a precision calibration sphere measuring 38.1 mm, with a known freshwater TS of -39.5 dB was used. A 17-mm sphere with a known freshwater TS of -45.8 dB was used for the 420-kHz system calibration. The calibration sphere was enclosed in a monofilament "cradle" and suspended in front of the transducer face at depths ranging from 3 to 11 m. At each depth, the system was enabled to actively ping on the standard target. Approximately 2,600 pings were collected at each depth interval. An off-axis distribution (OAD) file was generated and targets whose off-axis "Bn" fell between Bn ≤ 0.00 and Bn > -1.0 and Bn ≤ -1.0 and Bn > -2.0 were used to calculate an average target strength. Average target strength was then subtracted from the standard target strength to produce the calibration correction at a given depth. All depth corrections were then summed and the average taken to produce an overall average throughout the water column correction factor. This correction factor was then applied to the average target strength to give the adjusted average target strength. Results from a May 2007 data collection event indicated that a correction of -0.78 dB was necessary for the 200-kHz system (as given in the example in Table 1) and a system calibration of +0.79 dB was made to the 420-kHz system. These values were used for all subsequent data analyses. No calibration adjustments were necessary for either system during the March 2008 data collection event.

Table 1. In situ calibration results applied to the 200-kHz system during May 2007

File/System Frequency	Standard Target (dB)	Average Target Depth (m)	Avg Target Strength (dB)	Calibration Correction	Adjusted Average TS (dB)
File 1a, 200 kHz	-39.5	11.7	-40.37	-0.87	-39.60
File 1b, 200 kHz	-39.5	9.7	-40.15	-0.65	-39.36
File 1c, 200 kHz	-39.5	7.3	-40.38	-0.88	-39.60
File 1d, 200 kHz	-39.5	4.9	-39.75	-0.25	-38.97
File 1e, 200 kHz	-39.5	2.8	-40.74	-1.24	-39.96
Average			-40.28	-0.78	-39.50

Sturgeon Tethering Experiments. Tethering techniques have been used successfully to verify TS-TL relationships for numerous species (Hartman and Nagy 2005; Frouzova et al. 2005). Tethering is basically a means of placing an individual fish of known species identity and size characteristics within the transducer's beam axis at a measured distance. In the present study, the 200- and 420-kHz transducers were attached to an aluminum mount secured to the gunnel of the survey vessel that allowed downward vertical orientation of the beams. Atlantic sturgeon were caught in staked fyke nets at Herring Creek downriver from the study site, transported to Virginia Commonwealth University's Rice Center, and held in a net impoundment. Lengths (total and fork length in mm) and weight (kg) for each test fish were measured prior to acoustic data collection. Selected individuals were surgically attached to acoustically transparent monofilament lines behind the head and in front of the tail fin (Figure 2). The test fish was then suspended in a normal dorsal-ventral orientation directly below the face of the transducer at predetermined depths. Test sturgeon were not anesthetized and therefore had some limited swimming mobility, but could be maintained under the face of the appropriate transducer by adjusting either the forward or rear attached monofilament line in the proper direction. This ensured that the return echoes represented a dorsal-aspect orientation consistent with the derivation of Love's equation for estimation of TS. Twelve Atlantic sturgeon of varying sizes were tested using both the 200- and 420-kHz frequencies in May 2007 and March 2008. Water quality measurements taken during the experiments did not indicate the presence of water column stratification for any parameter tested. No thermocline was observed, as water temperatures varied by less than 0.1 °C from surface to bottom. No salinity (ppt) was detected at the study site and dissolved oxygen (mg/L) concentrations averaged slightly more than 7 mg/l throughout the water column.

Figure 2. Surgical attachment of monofilament to an Atlantic sturgeon during the tethering process.

Data Analysis. Each acoustic data file and associated echogram was reviewed to identify starting and ending ping numbers and target depth. The acoustic data were then processed using Hydroacoustic Data Analysis Software (HADAS) and all "accepted single targets" (AST) classified consistent with strings of echo returns that were collected under optimal conditions. HADAS processing parameters screened the data for all echo returns within the designated processing criteria (start/end ping numbers at designated depth interval) and accepted as a valid single target. The "bottom tracking" specification was defined as the deepest point of the processing window, i.e. the selected depth obtained from the initial review of the echogram. Target detection criteria were relaxed such that target returns between 0 and -60dB and up to 10 degrees off axis were accepted. This process was continued through multiple iterations to refine the analysis parameters used in final processing. HADAS processing thereby produced one to three sets of echograms and AST files for each sturgeon and frequency tested. Resultant AST file data were then combined per fish per frequency for further analysis. Thus acoustic backscatter cross-section values (Sigma) were obtained from subsections of "clean" data, averaged, and converted to TS (dB). Target strength (TS in dB) and acoustic cross-section backscatter (Sigma) data columns from each file were sorted in order of TS and plotted to visualize the TS distribution. An example histogram of TS distribution for Sturgeon #2 at 200 kHz is given in Figure 3. Initially only data for returns with the target near the average XY position were used. However, because the data were shown to be unaffected by occasional outliers, an average Sigma value was used. A plot showing distance off-axis in the X and Y planes for acoustic returns of Sturgeon #5 is given in Figure 4. All TS values were converted to acoustic backscatter cross-section ($\sigma = 4\Pi \cdot 10^{(TS/10)}$), which were then used to calculate mean and standard deviation (TS values are logarithmic and cannot be averaged) and then reconverted to TS ($=10 \log(\sigma/4\Pi)$). Length was calculated for each sturgeon tested using the specific TS-TL equation generated in this study and compared to actual total length. These measured and estimated TLs were compared to lengths calculated using Love's (1971) equation. Atlantic sturgeon used in the May 2007 experiments were captured in the James River, and released near the point of capture after the completion of testing. Maryland hatchery fish, used in March 2008, were not released into the James River after testing.

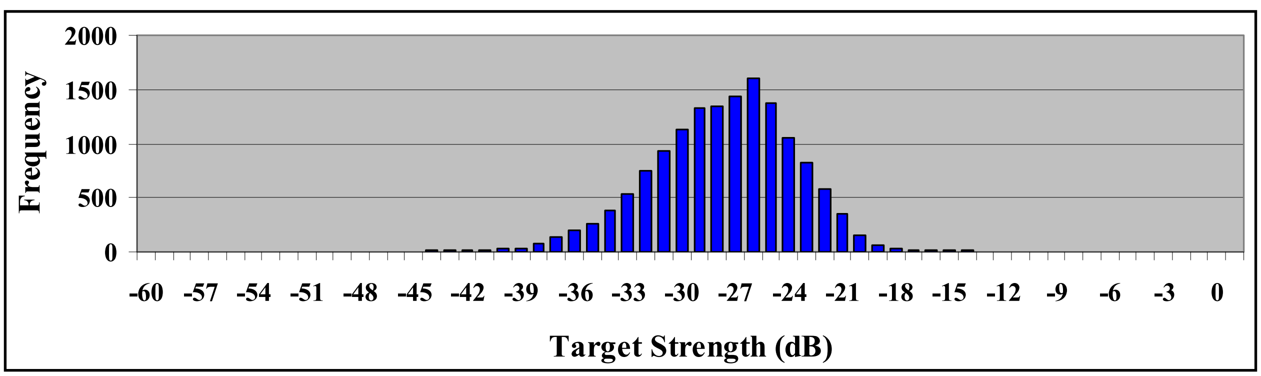

Figure 3. Target strength distribution for Sturgeon #2 at 200 kHz.

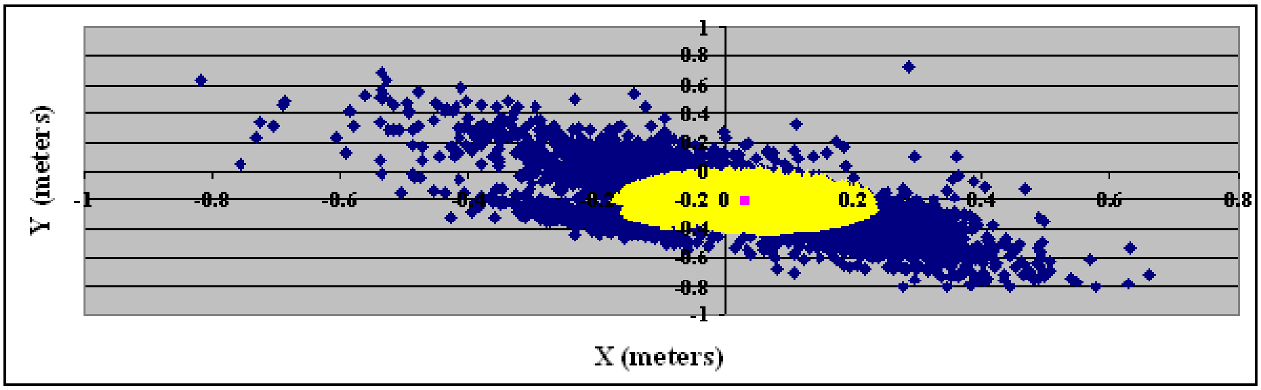

Figure 4. Distance (m) off-axis in the X and Y plane for acoustic returns of Sturgeon #5 at 420 kHz.

RESULTS:

May 2007 (200 kHz). Hydroacoustic data were successfully collected for five tethered Atlantic sturgeon on 9 May 2007. Data for an initial experiment were discarded when the target sturgeon became entangled in the tethering lines such that orientation could not be determined. Minor modifications were made to the tethering methodology and further tangling problems were avoided. To minimize stress on individual sturgeon, only single experiments were performed on each. Results for the 200-kHz frequency tests are given in Table 3. Each fish was measured and weighed prior to testing. Total lengths of tested specimens ranged from 77.4 to 91.1 cm, and fork lengths ranged from 67.0 to 76.8 cm. Average fish weight was 2.4 kg (range = 1.7-3.2 kg). Measured TS values ranged from -26.7 to -21.6 dB. Correspondence between measured TS and calculated TS (range = -24.8 to -26.2 dB) at 200 kHz is shown in Figure 5. Results for Sturgeon #4 were inconsistent in that the measured TS (-21.6 dB) is considerably different than values for the other four tested sturgeon. One possible explanation for this disparity is that this fish was the last to be tested, and testing occurred near the end of an ebb tidal cycle. Sediment degassing was prominent in the acoustic returns and probably skewed the results for this individual. Length for this fish was overestimated by both the authors' equation (+42.8 cm) and Love's equation (+78.2 cm). For the other four sturgeon tested, measured TS differed from calculated TS by $\leq$ 0.7 dB. Measured to calculated TL comparisons were made using the derived 200-kHz TS-TL equation (TS (dB) = 20 Log (mm) -64), and Love's dorsal-aspect equation. For the derived equation, calculated length differed from actual length by $\leq$ 7.2 cm (range -4.5 to +7.2 cm). Length was over- and underestimated for two of the four sturgeon, respectively. When applying Love's dorsal-aspect equation, TS was overestimated for all four sturgeon by 1.1 to 2.5 dB, or 12.6 to 32 cm. Measured to calculated sturgeon lengths are compared in Figure 6.

Table 3. Results from May 2007 tethering study of Atlantic sturgeon using 200- (b = -64) and 420- (b = -63) kHz frequencies

Fish ID #	Frequency	Length (cm)		Weight (kg)	Sigma Conversion to TS (dB)	Calculated TS (dB)	TS Diff: Measured vs. Calculated	Love's (dB)	Love's TS Diff	Length (cm)			
		Total	Fork							Derived Equation	Derived vs. Actual	Love's Equation	Love's vs. Actual
1	200	77.4	67.0	1.7	-26.7	-26.2	-0.5	-28.0	1.3	72.9	-4.5	90.0	+12.6
2	200	81.6	71.3	2.5	-26.5	-25.8	-0.7	-27.6	1.1	75.2	-6.4	92.9	+11.3
3	200	82.1	69.0	2.3	-25.2	-25.7	0.5	-27.5	2.3	87.2	+5.1	108.5	+26.4
4	200	88.7	76.0	2.3	-21.6	-25.0	3.4	-26.9	5.2	131.5	+42.8	166.9	+78.2
5	200	91.1	76.8	3.2	-24.2	-24.8	0.7	-26.6	2.5	98.3	+7.2	123.1	+32.0
1	420	77.4	67.0	1.7	-23.8	-25.2	1.4	-28.3	4.5	91.1	+13.7	132.8	+55.4
2	420	81.6	71.3	2.5	-23.9	-24.8	0.9	-27.8	4.0	90.5	+8.9	131.9	+50.3
3	420	82.1	69.0	2.3	-25.9	-24.7	-1.2	-27.8	1.9	71.3	-10.8	102.7	+20.6
4	420	88.7	76.0	2.3	-19.9	-24.0	4.1	-27.2	7.2	142.7	+53.9	212.3	+123.6
5	420	91.1	76.8	3.2	-24.7	-23.8	-0.9	-26.9	2.3	82.6	-8.5	119.8	+28.7

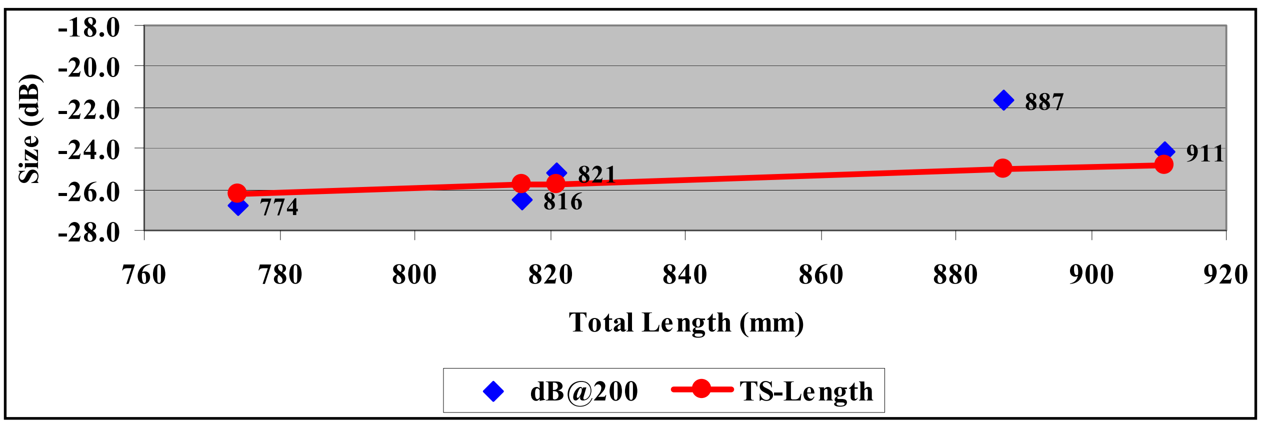

Figure 5. Measured TS in relation to calculated TS at 200 kHz.

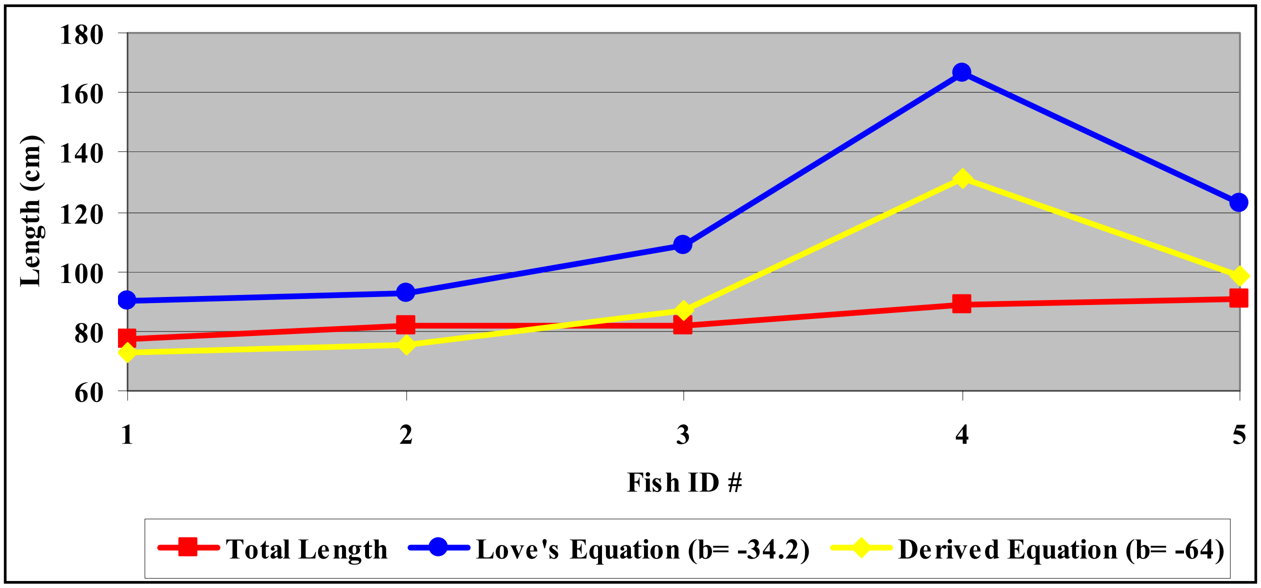

Figure 6. Comparison of measured and calculated total lengths at 200 kHz.

May 2007 (420 kHz). Data were collected simultaneously with a 420-kHz system. Results are presented in Table 3. Acoustic backscatter conversion to TS values ranged from -19.9 to -24.7 dB. As observed with the 200-kHz system, the TS for Sturgeon #4 diverged substantially from values for the other sturgeon tested. Measured and calculated TS differed by 4.1 dB based on the authors' equation and slightly more than 7 dB based on Love's equation, resulting in TL being overestimated by 53.9 and 123.6 cm, respectively. For the other four sturgeon, a 420-kHz TS-TL equation of TS (dB) = 20 Log (mm) -63 was derived. At 420 kHz, the relationship between measured TS and calculated TS-TL is given in Figure 7. Measured and calculated TS values differed by -0.9 to 1.4 dB. Based on these values, the authors' equation overestimated length for two of the four sturgeon tested by 8.5 and 13.7 cm, and underestimated length for two others by 8.5 and 10.8 cm. Lengths calculated using Love's dorsal-aspect TS-length equation differed from measured TL by 20 to 55 cm at 420 kHz, even larger disparities than observed for the 200-kHz data. Measured and calculated TL values are compared in Figure 8.

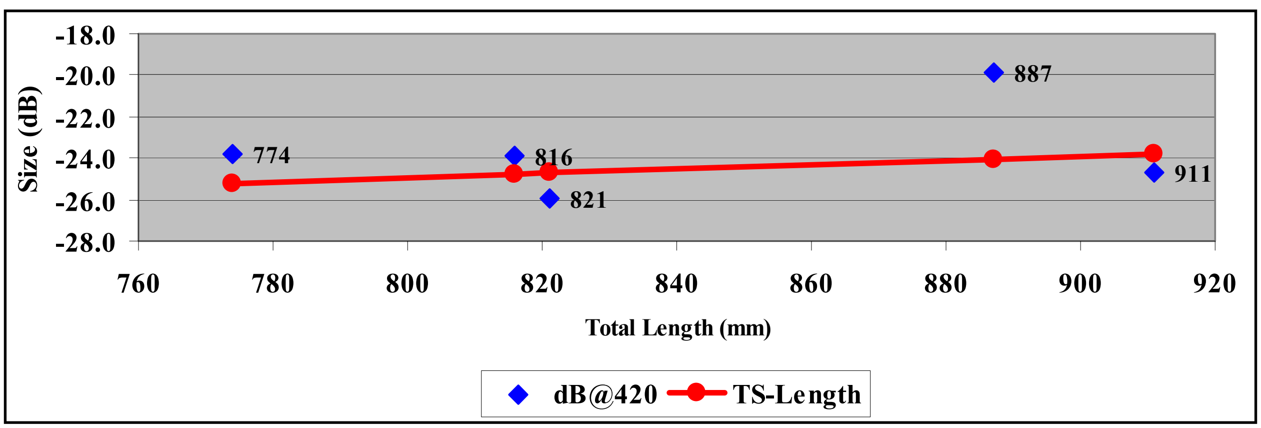

Figure 7. Measured TS in relation to calculated TS at 420 kHz.

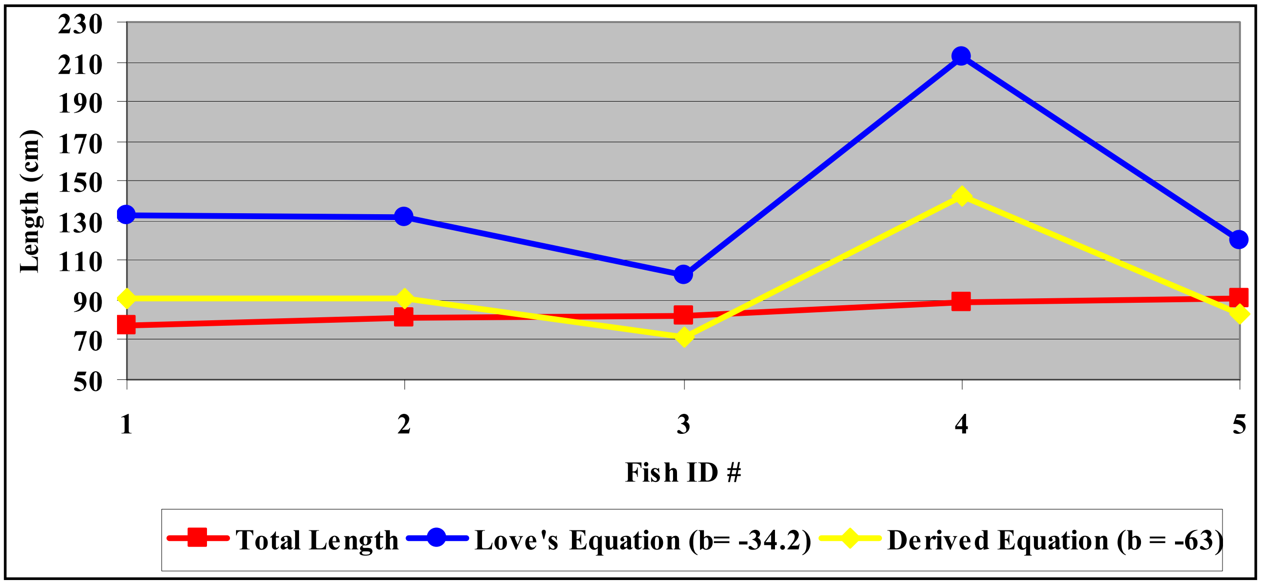

Figure 8. Comparison of measured and calculated total lengths at 420 kHz.

March 2008 (200 kHz). The second tethering data collection effort occurred in March 2008 in the same Dutch Gap Cutoff location. Results for the 200-kHz system are given in Table 4. Unlike previously tested native James River sturgeon, the March 2008 specimens were obtained from a Maryland hatchery. Six Atlantic sturgeon were tested, with lengths ranging from 41 to slightly less than 50 cm TL. Weights averaged 0.20 kg (range = 0.11 to 0.26 kg). Measured TS ranged from -34.2 to -39.8 dB at 200 kHz. Calculated TS differed from measured TS by -0.7 to +2.3 dB. From these data, the 200-kHz TS-TL equation was derived as TS (dB) = 20 Log (mm) -70dB. Based on this equation, TL ranged from 32.4 to 61.8 cm. When compared to actual TL the calculated lengths of two sturgeon were overestimated by 3.5 and 14.3 cm, whereas the calculated lengths of four other sturgeon were underestimated by 3.9 to 8.9 cm. The relationship of measured to calculated TS is given in Figure 9. Target strengths estimated by Love's equation ranged from 2.1 to 6.6 dB lower than expected, underestimating sturgeon actual lengths by 10.8 to 23.0 cm. This pattern varied considerably from the data obtained for the larger sturgeon tested in 2007, where all fish lengths were overestimated by Love's equation. Differences in measured and calculated TLs are shown in Figure 10.

Table 4. Results from March 2008 tethering study of Atlantic sturgeon using 200- (b = -70) and 420- (b = -67.9) kHz frequencies

		Length (cm)								Length (cm)			
Fish ID	Frequency	Total	Fork	Weight (kg)	Sigma Conversion to TS (dB)	Calculated TS (dB)	TS Diff: Measured vs. Calculated	Love's (dB)	Love's TS Diff	Derived Equation	Derived vs. Actual	Love's Equation	Love's vs. Actual
6	200	48.5	40.5	0.23	-37.0	-36.3	-0.7	-31.9	-5.1	44.6	-3.9	26.1	-22.4
7	200	45.5	39.5	0.23	-38.2	-36.8	-1.4	-32.4	-5.8	38.7	-6.8	22.5	-23.0
8	200	47.5	40.0	0.26	-34.2	-36.5	2.3	-32.0	-2.1	61.8	+14.3	36.7	-10.8
9	200	43.4	35.5	0.20	-36.6	-37.3	0.7	-32.8	-3.8	46.9	+3.5	27.5	-15.6
10	200	45.5	38.0	0.17	-37.7	-36.8	-0.8	-32.4	-5.3	41.4	-4.1	24.2	-21.3
11	200	41.3	34.4	0.11	-39.8	-37.7	-2.1	-33.2	-6.6	32.4	-8.9	18.7	-22.6
6	420	48.5	40.5	0.23	-34.9	-34.2	-0.7	-32.2	-2.7	44.9	-3.6	35.1	-13.4
7	420	45.5	39.5	0.23	-35.2	-34.7	-0.5	-32.7	-2.5	43.1	-2.5	33.5	-12.0
8	420	47.5	40.0	0.26	-34.7	-34.4	-0.3	-32.3	-2.3	45.9	-1.6	35.8	-11.7
9	420	43.4	35.5	0.20	-34.4	-35.2	0.7	-33.1	-1.3	47.3	+3.9	37.0	-6.4
10	420	45.5	38.0	0.17	-34.2	-34.7	0.5	-32.7	-1.5	48.3	+2.8	37.8	-7.7
11	420	41.3	34.4	0.11	-35.4	-35.6	0.2	-33.5	-1.9	42.2	+0.9	32.8	-8.5

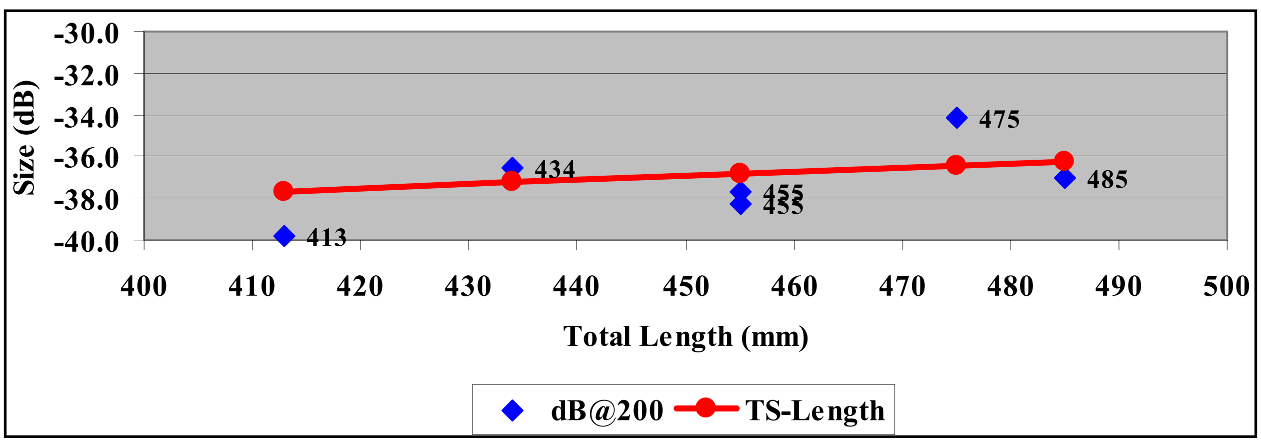

Figure 9. Measured TS in relation to calculated TS at 420 kHz.

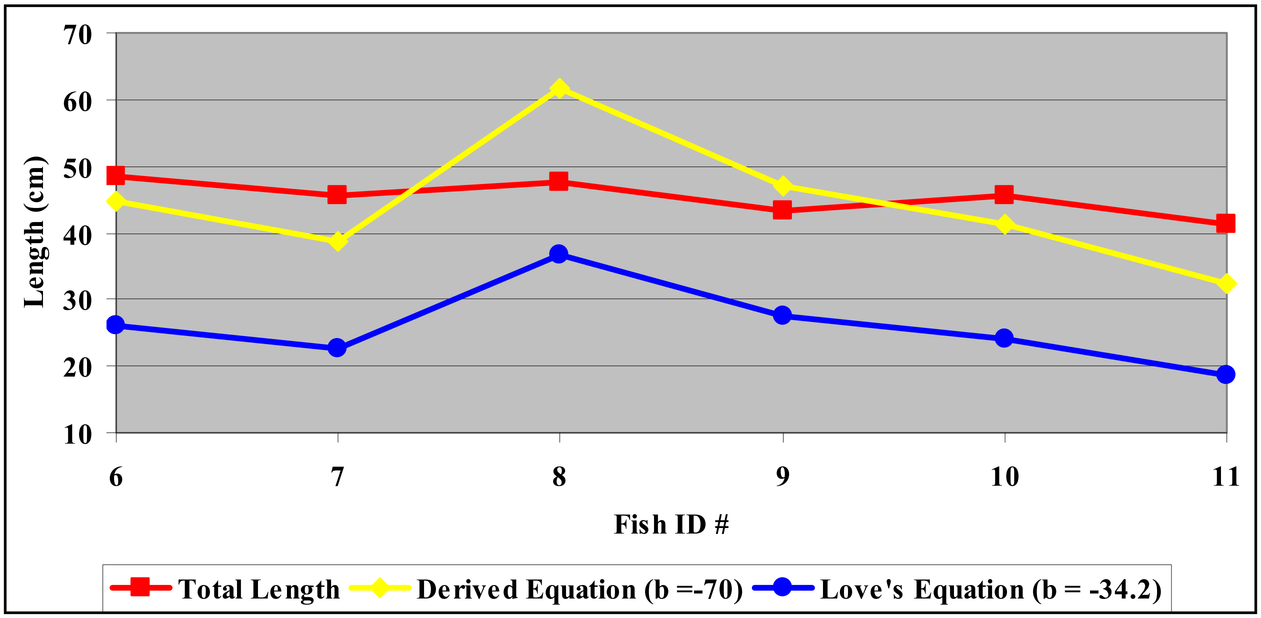

Figure 10. Comparison of measured and calculated total lengths at 200 kHz.

March 2008 (420 kHz). Data collected using the 420-kHz system are summarized in Table 4. Measured TS ranged from -34.2 dB to -35.4 dB. Differences between measured and calculated TS values were less than $\pm$ 0.7 dB. Figure 11 indicates a close fit between measured and calculated TS for all six sturgeon tested. Based on these data, a 420-kHz TS-TL sturgeon equation was derived as TS (dB) = 20 Log (mm) -67.9 dB. Applying this equation the lengths of three of the six sturgeon were underestimated by less than 4 cm (range = 1.6 to 3.6 cm) and the remaining three sturgeon lengths were overestimated by less than 4 cm (range = 0.9 to 3.9 cm). Love's equation underestimated TS by 1.3 to 2.7 dB, resulting in lengths underestimated by 6.4 to 13.4 cm. The degree to which Love's equation underestimated average TL was less at 420 kHz frequency (mean = 10 cm) than at 200 kHz (mean = 19.3 cm). Measured and calculated TLs are compared in Figure 12.

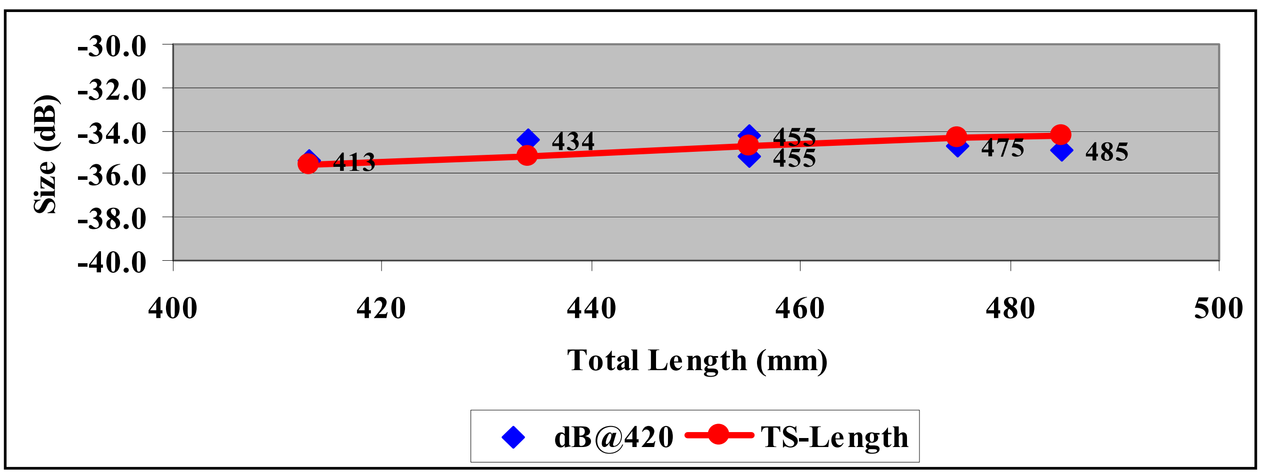

Figure 11. Measured TS in relation to calculated TS at 420 kHz.

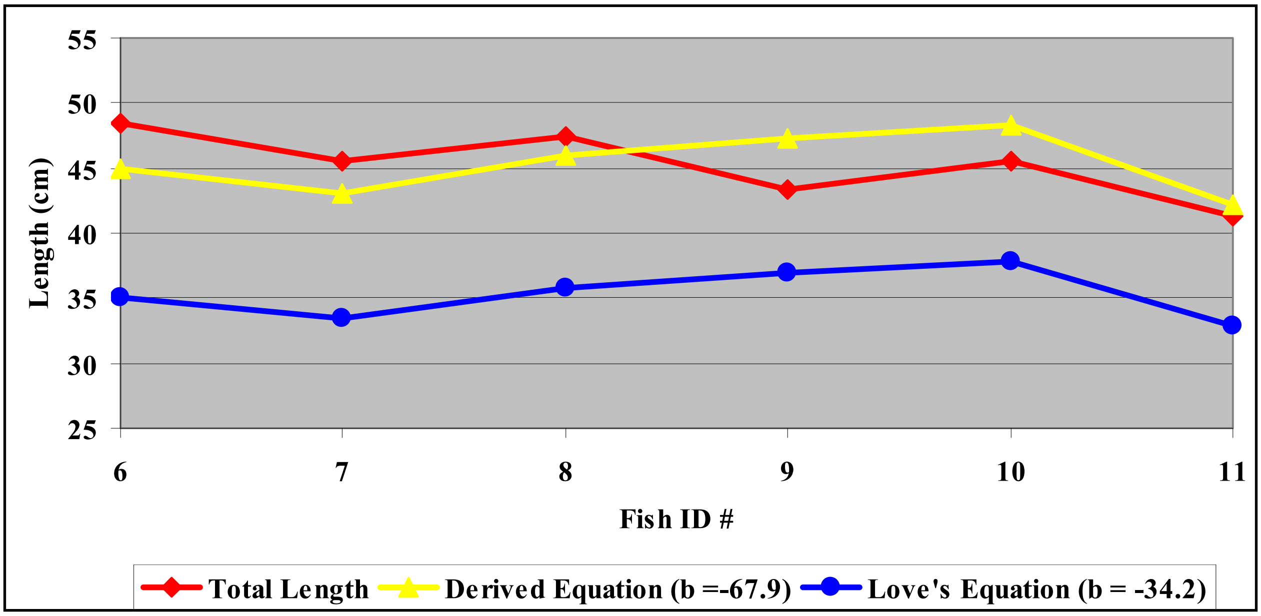

Figure 12. Comparison of measured and calculated total lengths at 420 kHz.

Combined Results. Although the constraints of small sample size can contribute to observed variation in the data, the substantial differences noted in the derived TS-TL equations between the two experimental groups of Atlantic sturgeon were somewhat surprising. The authors had anticipated refining a single generic equation for Atlantic sturgeon, with perhaps two variations for the two tested frequencies. Other than the distinct length differences in the tested sturgeon groups in each year, little evidence of other factors contributing to the different TS-TL relationships can be discerned. Although many potential factors can influence echo return values, it is suspected that different weight-to-length ratios between the generally larger 2007 and smaller 2008 sturgeon groups may have affected TS values. Fish length (cm) to weight (kg) differences are clearly evident in Figure 13. Consequently, a single generic equation could produce misleading length estimates if applied across a wide range of actual lengths. For example, combining the derived equations into the TS (dB) = m + Log (mm) + b format, where m=20 and b is derived would produce TS (dB) = 20Log (mm) -66.7 at 200 kHz and TS (dB) = 20Log (mm) -65.0 at 420 kHz. The relationship of TS measured in situ to the TS-length equation for both 200 kHz and 420 kHz is shown in Figures 14 and 15. Both frequencies exhibited a similar pattern in that a single TS-TL equation underestimated lengths of smaller sturgeon and overestimated lengths of larger sturgeon.

Combined results for the 200-kHz samples are given in Table 5. At 200 kHz, calculated TS for larger sturgeon (70-91 cm) were 2 to 3.4 dB greater than measured values, yielding calculated lengths 20 to 43 cm greater than measured lengths. For the smaller sturgeon (< 50 cm), calculated TS values were 1.0 to 5.4 dB lower than those measured in situ. These values correspond to TLs 5.2 to 19.1 cm smaller than actual fish lengths. Love's equation performed somewhat better than the combined equation where b = -66.7 at 200 kHz, but only for the larger fish. Total lengths were overestimated by 11.3 to 31.9 cm, but the overall average (mean = 20.6 cm) was lower than for the derived equation (mean = 30.7 cm). For the smaller sturgeon, Love's equation underestimated actual lengths by an average of 19.4 cm (range = 10.8 to 23.0 cm), as compared to an average of 15 cm using the combined equation. Measured and calculated sturgeon lengths are compared in Figure 16.

Combined data for the 420-kHz system are given in Table 6. At this frequency, both Love's and the derived equation (b = -65) performed equally well for smaller sturgeon. Love's equation underestimated sturgeon length by 6 to 13 cm (mean = 9.9 cm), as compared to 9.6 to 16.4 cm (mean = 12.8 cm) for the derived sturgeon equation. However, Love's equation was very unreliable in predicting TL for the larger sturgeon tested, overestimating TL (excluding fish #4) by an average of 38.8 cm (range = 20.6 to 123.6 cm), a factor of 1.5 to nearly 3 times that estimated by the derived (mean = 22.5 cm) equation (Figure 17).

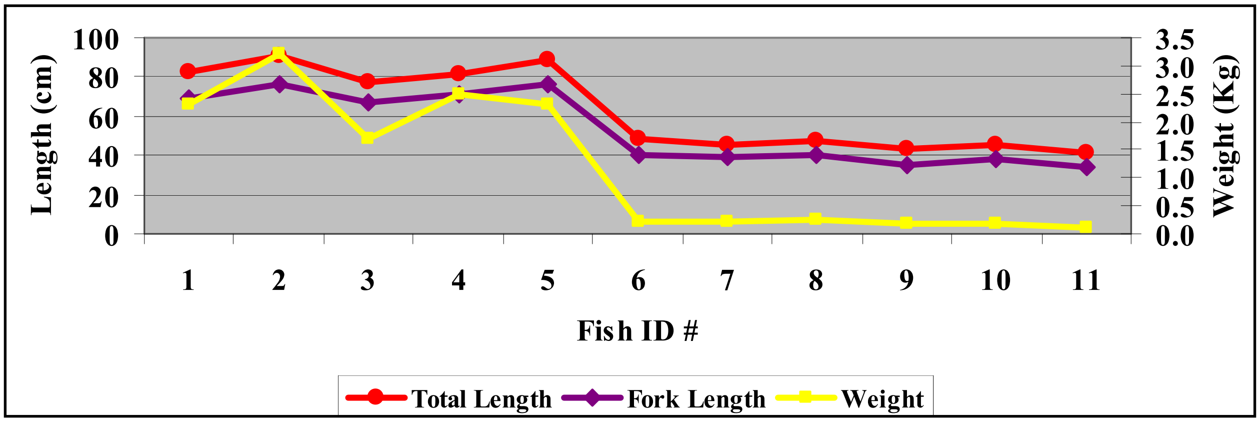

Figure 13. Comparison of total and fork length (cm) to weight (Kg)

Table 5. Combined results for all sturgeon tethering experiments at 200kHz. (Derived equation based on b = -66.7)

Fish ID	Total Length (cm)	Fork Length (cm)	Weight (kg)	Sigma Conversion to TS (dB)	Calculated TS (dB)	TS Diff Measured vs. Calculated	Length (cm)			
							Derived Equation	Derived vs. Actual	Love's Equation	Love's vs. Actual
1	77.4	67.0	1.7	-26.7	-28.9	2.2	99.5	+22.1	90.0	+12.6
2	81.6	71.3	2.5	-26.5	-28.5	2.0	102.6	+20.9	92.9	+11.3
3	82.1	69.0	2.3	-25.2	-28.4	3.2	118.9	+36.8	108.5	+26.4
4	88.7	76.0	2.3	-21.6	-27.7	6.1	179.4	+90.7	166.9	+78.2
5	91.1	76.8	3.2	-24.2	-27.5	3.4	134.2	+43.0	123.1	+31.9
6	48.5	40.5	0.23	-37.0	-33.0	-4.0	30.5	-18.0	26.1	-22.4
7	45.5	39.5	0.23	-38.2	-33.5	-4.7	26.5	-19.0	22.5	-23.0
8	47.5	40.0	0.26	-34.2	-33.2	-1.0	42.3	-5.2	36.7	-10.8
9	43.4	35.5	0.20	-36.6	-34.0	-2.6	32.1	-11.3	27.5	-15.9
10	45.5	38.0	0.17	-37.7	-33.5	-4.1	28.3	17.1	24.2	21.4
11	41.3	34.4	0.11	-39.8	-34.4	-5.4	22.2	-19.1	18.7	-22.6

Table 6. Combined results for all sturgeon tethering experiments at 420kHz. (Derived equation based on b = -65)										
							Length (cm)			
Fish ID	Total Length (cm)	Fork Length (cm)	Weight (kg)	Sigma Conversion to TS (dB)	Calculated TS (dB)	TS Diff Measured vs. Calculated	Derived Equation	Derived vs. Actual	Love's Equation	Love's vs. Actual
1	77.4	67.0	1.7	-23.8	-27.2	3.4	114.7	+37.3	132.8	+55.4
2	81.6	71.3	2.5	-23.9	-26.8	2.9	113.9	+32.3	131.9	+50.3
3	82.1	69.0	2.3	-25.9	-26.7	0.8	89.7	+7.6	102.7	+20.6
4	88.7	76.0	2.3	-19.9	-26.0	6.1	179.6	+90.9	212.3	+123.6
5	91.1	76.8	3.2	-24.7	-25.8	1.1	103.9	+12.8	119.8	+28.7
6	48.5	40.5	0.23	-34.9	-31.3	-3.6	32.1	-16.4	35.1	-13.4
7	45.5	39.5	0.23	-35.2	-31.8	-3.4	30.8	-14.6	33.5	-11.9
8	47.5	40.0	0.26	-34.7	-31.5	-3.2	32.9	-14.7	35.8	-11.7
9	43.4	35.5	0.20	-34.4	-32.3	-2.2	33.9	-9.6	37.0	-6.4
10	45.5	38.0	0.17	-34.2	-31.8	-2.4	34.6	-10.9	37.8	-7.7
11	41.3	34.4	0.11	-35.4	-32.7	-2.7	30.2	-11.1	32.8	-8.4

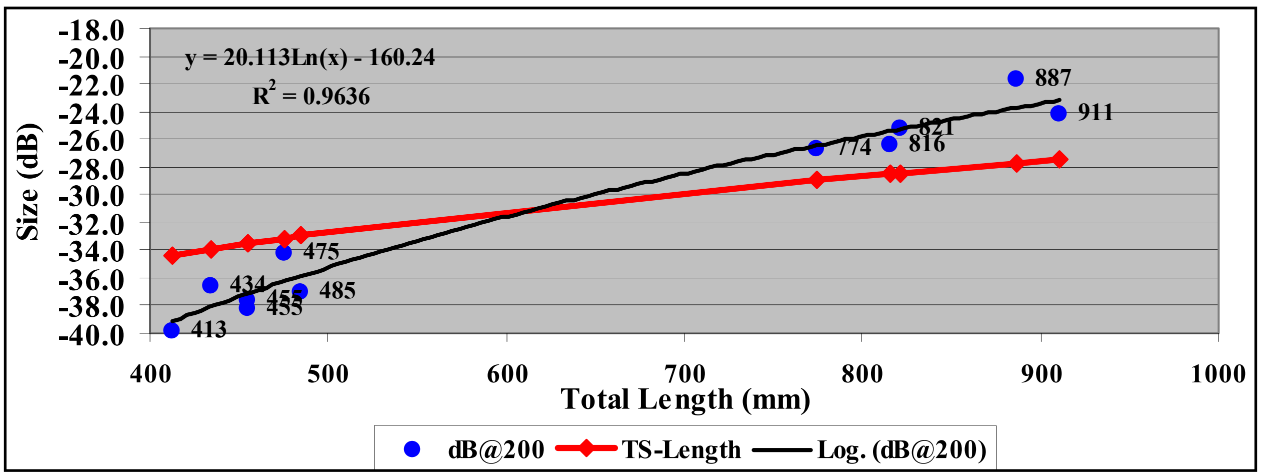

Figure 14. Relationship between measured total length and the natural log of calculated TS-length at 200 kHz.

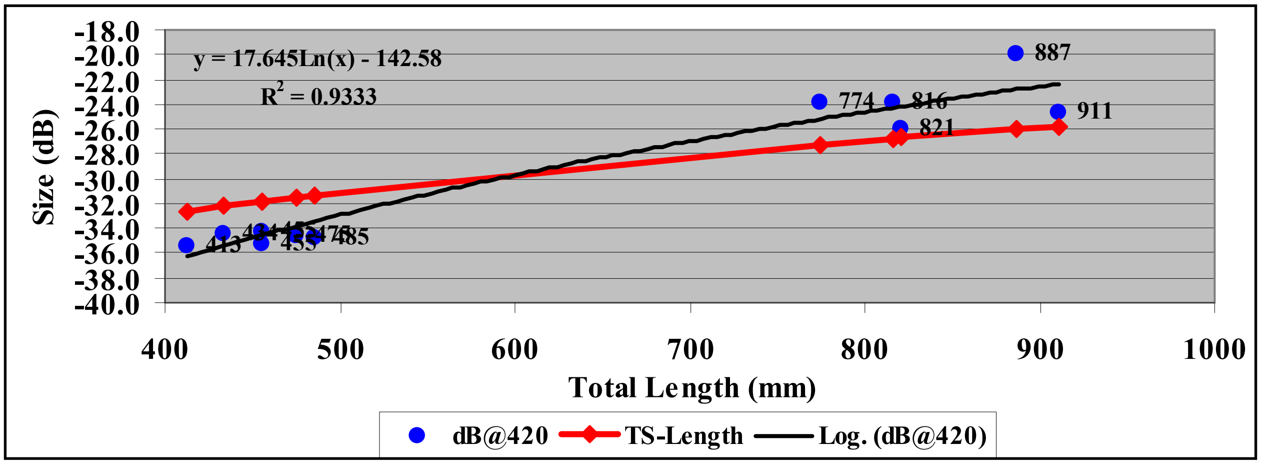

Figure 15. Relationship between measured total length and the natural log of calculated TS-length at 420 kHz.

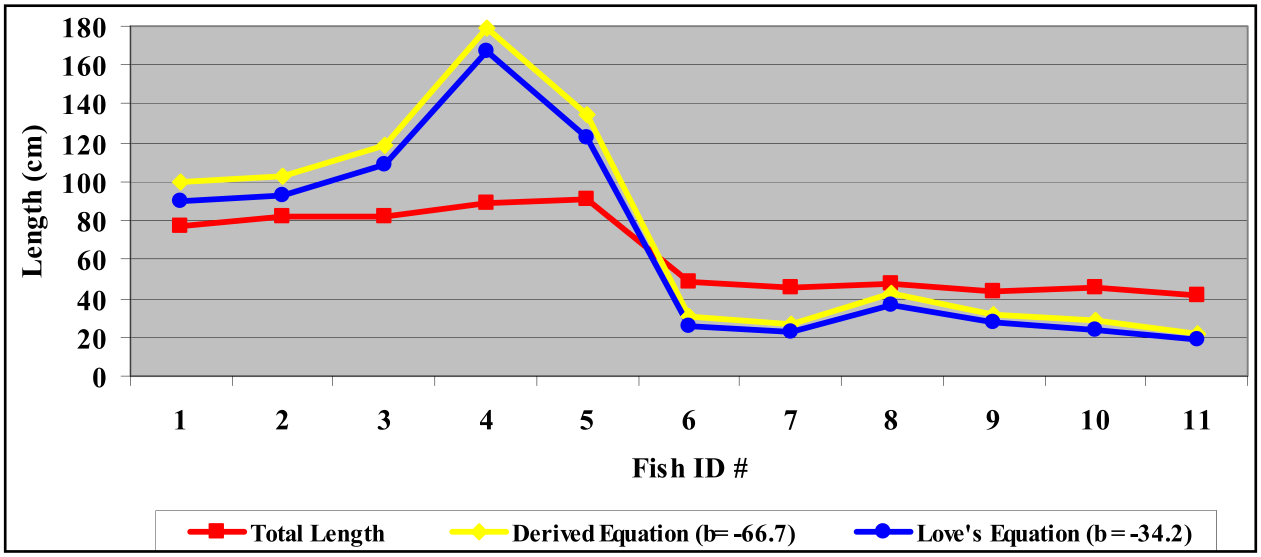

Figure 16. Measured versus calculated total length at 200 kHz.

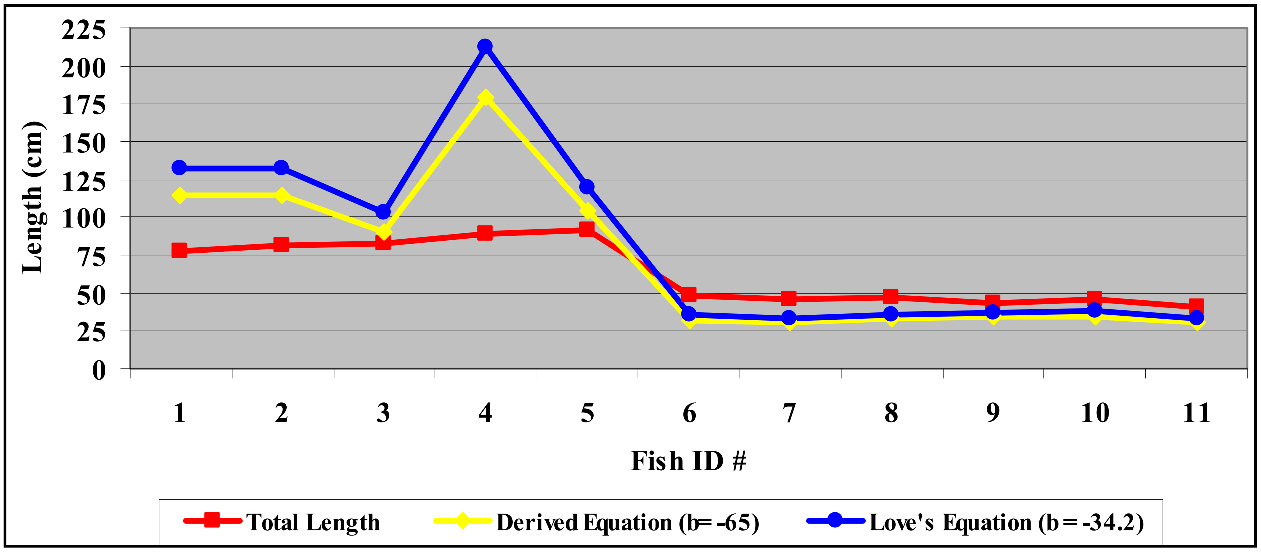

Figure 17. Measured versus calculated total length at 420 kHz.

DISCUSSION: Although fisheries hydroacoustic techniques have been used for decades, their application in impact assessments, particularly involving dredging operations, has been limited. A major limitation in pursuing impact assessment applications is the lack of a robust capability to discriminate the taxonomic identities of acoustic targets and their sizes (MacLennan and Menz 1996; McClatchie et al. 1996). Presently "ground truthing" of hydroacoustics data is accomplished by means of conventional netting techniques. Additionally data are screened by a logical stepwise process of elimination, whereby existing knowledge of behaviors and size characteristics of fishes known to occupy the surveyed body of water is used to determine probable identities of acoustic targets. Historically, hydroacoustic techniques have proven suitable for stock assessments where the fish assemblage was dominated by a single species. Recently, greater attention has been given to overcoming limitations associated with target species discrimination (Burwen and Fleischman 1998). Nealson and Brundage (2007) studied the feasibility of shortnose sturgeon detection with a 200-kHz split-beam system with a 15-deg beam angle. They listed 13 variables that could potentially be used to discriminate sturgeon from other species. These included TS, target depth, fish distance above the bottom, number of echo returns, pulse width of the returning echoes, and within-fish variability of each parameter. Nealson and Brundage (2007) concluded that TS and distance above the bottom were promising discriminators of shortnose sturgeon from other species at their site.

"Remote sensing" of fish populations by non-destructive methods remains an elusive goal of fisheries biologists. Fishery hydroacoustics offers great promise as a means to locate fishes precisely within large volumes of water, and to accurately estimate fish density, size frequency, and biomass without excessive resort to conventional netting methods. Increasing confidence in species discrimination of acoustic targets will greatly enhance the utility of fishery resource surveys for impact assessment applications, particularly with regard to species that have protected status or are experiencing significant population declines.

Accurate target strength data are needed to convert echo-integrated measurements to abundance or biomass estimates. Thus an understanding of the relationship between TS and fish length cannot be overstated. Clearly the longstanding acceptance of Love's (1971) and Foote's (1987) dorsal-aspect equations is an inadequate basis for many hydroacoustic survey applications. Although Love's equation provided reasonable estimates of fish length for some species (e.g., larval perch, *Perca fluviatilis*) (Frouzova and Kubecka 2004), it does not appear to fit sturgeon targets. Likewise, Hartman and Nagy (2005) reported that Love's (1971) and Foote's (1987) equations tended to greatly underestimate TS. They reported that TS values were underestimated by 3 to 4 dB by Love's equation and by as much as 9 to 10 dB by Foote's equation for striped bass (*Morone saxatilis*) and white perch (*Morone americana*). Results indicate a lack of predictive capability for Love's equation applied to Atlantic sturgeon. Discrepancies in TS can be significant when an equation has been derived for one species or a group of similar species and then applied to a species with clearly different morphology. Love's (1971) equation was based on echo return data for several common coastal species, and Foote's equation was based on similar data for herring. Sturgeon morphology is quite distinct from other boney fishes, which may account for departures from the previously used equations.

TS-length equations derived in this study gave relatively close approximations of sturgeon TS, within 0.5 to 1.4 dB for the larger size class and 0.2 to 2.1 dB for the smaller size class. TS measurements obtained with the 420-kHz system were found to be relatively accurate when testing the smaller sturgeon, whereas the 200-kHz system yielded closer TS values for larger sturgeon. Observed TS differences may be related to differences in fish orientation to each of the transducers as well as differences in transducer beam angle. For example, if the test subject was directly on axis for the 6-deg beam 200-kHz transducer, then it was slightly off-axis for the 10-deg beam 420-kHz system, given that the 200-kHz transducer was positioned directly forward of the 420-kHz unit. Simmonds and MacLennan (2005) reported that with the exception of a perfectly spherical target, or one that is very small compared to the wavelength, the scattered sound field depends on the shape of the target and how it is positioned relative to the incident wave direction. Target strength is also strongly influenced by tilt angle, i.e. the angle between the long axis of the fish to the transmitted pulse. The tilt angle is considered positive if the fish head is oriented in an upward direction and negative if the head is in a downward orientation. This has the effect of either reinforcing or reducing the echo amplitude. Turbid waters at the in-river test site of the present study prevented visual confirmation of sturgeon orientation and tilt angle. Further studies involving testing of free-swimming sturgeon in a deep tank under much more controlled conditions are planned. Because the tethered sturgeon had some freedom of movement, an assumption was made that the fish oriented itself in the direction of the current in a normal swimming posture. The possibility exists, however, that the tethering apparatus could have altered behavior and orientation, thereby influencing target strength.

Populations of many sturgeon species have experienced declines due to over-fishing, loss of spawning, nursery, or foraging habitat, migratory blockage by locks and dams, impaired water quality, and other causes. For many sturgeon species data gaps concerning accurate population abundance estimates, habitat utilization patterns, and timing of use of migratory corridors remain, making an effective determination of the status of any given species difficult. Fisheries hydroacoustics methodologies could address important knowledge gaps in a non-destructive, cost-effective manner. Researchers have three basic options with regard to establishing target strength to length relationships for their species of interest. Either a general equation like Love's (1971) equation is accepted, a TS-length relationship developed for the species to be studied, or if possible one can be obtained from the existing scientific literature. Simmonds and MacLennan (2005) provide a recent extensive summary of target strength measurements for a variety of species. However, only a very small fraction of species of interest have target strength data available in the current literature. Applying an equation from the literature has been shown by the present study to be undesirable for fundamental technical reasons.

CONCLUSION: Results of the present study emphasize the necessity of determining species-specific TS-length relationships for sturgeon before fisheries hydroacoustics studies of sturgeon (or many other species) can be pursued. Using conventional log (base 10) equation structure, TS-TL equations were derived with acceptable goodness of fit for data describing Atlantic sturgeon in two distinct size categories. However, when the data for all tested sturgeon were combined to produce a single TS-TL, the collective data fit rather poorly. Using a natural log transformation of the data greatly improved the goodness of fit (R^2 = 0.964 @200kHz; R^2 = 0.933 @420kHz). However natural log-based TS-length equations of the form TS (dB) = m * Ln(mm) +b have not previously been reported in the literature. Additional measurements obtained under controlled laboratory conditions may be required to fully elucidate sturgeon TS-TL relationships. It is encouraging that echo returns from sturgeon appear to have unique attributes that may with further investigation lead to improved acoustic taxonomic discrimination. Unique aspects of sturgeon morphology may provide new insights into interpretation of echo returns. Additional testing of Atlantic sturgeon representing a wider size range is planned to supplement the studies to date. Current results lay a foundation for development of a practical, reliable capability for surveying waterways suspected of being occupied by sturgeon or other species of interest.

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> Reine, K., D. Clarke, C. Dickerson, C. Hager, M. Balazik, G. Garmin, A. Spells, and C. Frederickson. 2010. *The relationship between acoustic target strength and body length for Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus)*. ERDC TN-DOER-E27. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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